AN EXPERIMENTAL INVESTIGATION OF PRESSURE ATTENUATION IN TYPICAL MISSILE PLUMBING SYSTEMS SUBJECTED TO SHOCK WAVE INPUTS - PART I

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AN EXPERIMENTAL INVESTIGATION OF PRESSURE

ATTENUATION IN TYPICAL MISSILE PLUMBING SYSTEMS

SUBJECTED TO SHOCK WAVE INPUTS - PART I

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NOTATION

C - empirical constant

D - tube inside diameter, in.

K - empirical constant

L - tube length, ft.

P_I - input pressure, psig

P_R - response pressure, psig

SUMMARY

An experimental investigation was conducted to determine the pressure attenuation of small diameter tubing, with a fixed volume attached to the downstream end, subjected to a shock wave input. The tubing tested was representative of the type found in the plumbing of missile pressure-sensing instrumentation systems.

A shock wave was generated by rupturing a diaphragm on one end of a closed tube filled with air. The wave so formed propagated down the test specimen and into the volume. A pressure-sensing transducer was connected to the upstream end of the test specimen, and another transducer was connected to the volume. These transducers relayed the pressure fluctuations of the shock wave to a recording oscillograph. The tubing tested had inside diameters of 0.370 and 0.242 inches and ranged in length from one to 15 feet. Each test specimen was subjected to shock waves formed by shock tube pressures ranging from 50 to 1000 psig.

It was determined that the maximum response pressure, $P_{R_{max}}$, could be approximated by the empirical relation

$$P_{R_{max}} = C\ P_{I_{max}}^{0.964}$$

or by the more simple, but less accurate, empirical relation

$$P_{R_{max}} = K\ P_{I_{max}}$$

The constants C and K are functions of the test system geometry.

It was also determined that tube diameter has much more effect on $P_{R_{max}}$ than tube length.

CHAPTER I

INTRODUCTION

Many of the modern missiles are equipped with pressure-sensing instruments. These instruments may be used to record the ambient pressure during the missile's trajectory, or they may be used as an arming device to detonate the missile at a predetermined pressure altitude. Ambient air enters a small bore tube at the missile's surface and travels along this tube to the pressure-sensing instrument. The accuracy of such an instrument is affected by extraneous pressure fluctuations in the tube. An explosion near a missile will produce a shock wave which propagates down the small bore tube to the pressure-sensing instrument. This shock wave could possibly cause large extraneous pressure fluctuations or cause a premature detonation of a missile armed with a pressure-sensing device.

The objective of this research is to obtain a relationship for the pressure attenuation of shock waves propagating in tubes typical of those in missile plumbing systems. These relations could be used to design a mechanism to block a shock wave before it reached the instrumentation of a missile. Kilburg (Reference 1) has extended this research to determine the effect of straight-through fittings on the pressure attenuation of shock waves in systems identical to the systems used in this research.

CHAPTER II

APPARATUS

All tests were conducted at Research Area Number Two of the Georgia Institute of Technology. The general layout of the apparatus is shown in Fig. 1, and an exploded view of the test apparatus is shown in Fig. 2.

Air was supplied for the tests by a gasoline engine powered, four-stage, 20 cfh, 3000 lb air compressor (Ingersoll-Rand Model GC-50-BW). The air was fed from the compressor storage tank through 1/4 in. extra-heavy copper tubing to a control board. A schematic diagram of the control board is shown in Fig. 3. A 3000-psig gauge was connected in the air line to measure the pressure in the compressor storage tank, and a 1000-psig gauge was connected in the air supply line to the shock tube. An air line was connected to the test system for the purpose of checking for leaks and calibrating the recording instruments. A bleed-off line was installed to bleed air from the shock tube or test system when desired. All air lines were 1/4 in. extra-heavy copper tubing, and all connections were made with flare tube fittings.

The shock tube was made from an extra-heavy, 4-1/2 in. outside diameter, steel pipe. The pipe was 7 ft. 7-1/2 in. in length with an inside diameter of 3-1/2 in. which was necked down to 2 in. at the downstream end to give an inside volume of 840 cu in. A blank flange sealed the upstream end of the pipe, and the downstream end was sealed with Mylar Polyester Film diaphragms. The shock tube was mounted out-of-doors on a reinforced wood table which was shock mounted to a concrete pad. A circular shaped 0.01 in. diameter steel wire was sandwiched between the diaphragms as shown in Fig. 4. An electrical power line was connected through a step-down transformer to the steel wire for the purpose of rupturing the diaphragms during an experimental test. The electric current heated the steel wire sufficiently to burn a portion of the diaphragms, and thus allowed the high pressure air to escape with a shock wave front.

A 2 in. diameter nozzle was attached to the downstream end of the shock tube with the diaphragms located between the nozzle and the tube (see Fig. 4). The nozzle was used so that the shock wave would not lose a large portion of its strength to the atmosphere before entering the pickup tube. The entrance of the pickup tube could not be placed close to the diaphragm because the burned portion would strike it during a test run.

The test system consisted of a pickup tube (see Fig. 5), the test specimen, and a cylindrical volume (see Fig. 6). The pickup tube was mounted on a raised concrete pad in line with the shock tube. Flare tube fittings were used to connect the upstream end of the test specimen to the pickup tube and the downstream end to the volume. These fittings were bored to an inside diameter equal to that of the test specimen. The test tubes were standard steel tubes with inside diameters of 0.370 in. and 0.242 in. and ranging from one to 15 ft. in length (see Table 1). Pressure-sensing transducers were connected to the pickup tube (to record the input pressure) and to the volume (to record the response pressure).

The transducers (Statham Temperature Compensated Pressure Transducers, Model No. PG 10 TC a - 1M - 350) were rigidly mounted to the concrete pad and connected to the pickup tube and volume by 15 in. length, heavy pressure, flexible hoses. Therefore, the effect of any mechanical vibrations which occurred during the tests were minimized.

The transducers were connected through a multi-channel amplifier to a Consolidated type 5-114 recording oscillograph as shown in Fig. 7. Two Sanborn recorders were connected to the lines between the amplifier and oscillograph to monitor the experiments.

CHAPTER III

PROCEDURE

The following test procedure was used for all tube sizes examined. The compressor was started and time was allowed for the pressure in the storage tank to reach 1300 psig. An air supply line was connected to the volume and a plug inserted in the entrance of the pickup tube. Air was fed into the system until a pressure of 850 psig was obtained. All valves on the control board were then closed, and the system was checked for leaks by soaping all the fittings and observing the gauge. If leaks were present they would be indicated by a drop in pressure on the gauge, and soap bubbles would form on the fittings having a leak. After any leaks present were corrected the air was bled from the system. The instrumentation was calibrated for the amplifier attenuation settings used by recording atmospheric pressure and a known pressure for each attenuation setting. The air line to the volume was then disconnected and replaced by a plug, and the plug in the pickup tube was removed.

The diaphragms (with the steel wire) were placed on the downstream end of the shock tube, and the nozzle was then bolted to the tube. The entrance of the pickup tube was carefully centered and placed about 1/8 in. inside the nozzle (see Fig. 8). The amplifier attenuation was set to the value corresponding to the shock tube pressure to be used (see Table 2). Air was fed into the shock tube until the proper pressure was obtained and then all valves on the control board were closed. The Sanborn recorders and recording oscillograph were turned on and a current was sent through the steel wire between the diaphragms. This ruptured the diaphragms, and the resulting shock wave then traveled down the nozzle and into the test system. The instruments were then switched off, and the Sanborn recorders were viewed to see if the results appeared reasonable. The system was calibrated again after the air line was connected to the volume and the plug inserted in the pickup tube. The nozzle was removed and the ruptured diaphragms were replaced with new ones for the next run.

The sizes of the specimen tested are given in Table 1. Each specimen was tested at shock tube pressures of 50, 100, 200, 500, 700, and 1000 psig. The proper diaphragms for each shock tube pressure are given in Table 3.

After sufficient experimental tests were performed to consume the paper in the recording oscillograph, the magazine was removed and the paper was developed. A typical recording of the input pressure and response pressures is shown in Fig. 9.

A calibration constant for each transducer and for each amplifier attenuation setting was calculated by the following method: The distance from the atmospheric line to the known pressure line on the oscillograph paper was measured for each calibration of that particular attenuation setting. An average value of these distances for all the calibrations was computed, and the calibration constant was obtained by dividing the known value of the pressure (psig) by this average distance. The value of the pressure in an experimental test could then be determined by measuring the distance from the atmospheric line to the desired pressure line and multiplying this distance by the proper calibration constant. This system of computing pressures introduced errors no greater than $\pm$ 4 per cent.

CHAPTER IV

RESULTS

The maximum input pressure, $P_{I_{max}}$, and maximum response pressure, $P_{R_{max}}$, were calculated from the oscillograph records for each experimental run and are presented graphically in Fig. 10. It was noted that for a constant shock tube pressure the maximum input pressure varied for each test specimen. As mentioned previously, the accuracy of the calculated pressures were within $\pm$ 4 per cent which accounts for these differences.

A close examination of the values of $P_{I_{max}}$ and $P_{R_{max}}$ revealed that $P_{R_{max}}$ could be approximated by the empirical relation

$$P_{R_{max}} = CP_{I_{max}}^{0.964}$$

It was also found that $P_{R_{max}}$ could be represented by the more simple, but less accurate, empirical relation

$$P_{R_{max}} = KP_{I_{max}}$$

The constants C and K are functions of tube length, tube diameter, and volume size. The following empirical relations were obtained for each constant as a function of the tube length, L:

$$C_1 = - 0.000082L^3 + 0.00319L^2 - 0.0528L + 0.675 \quad (D = 0.242 \text{ in.})$$

$$C_2 = - 0.000262L^3 + 0.00942L^2 - 0.1198L + 1.239 \quad (D = 0.370 \text{ in.})$$

$$K_1 = -0.000060L^2 + 0.00231L^2 - 0.0400L + 0.536 \quad (D = 0.242 \text{ in.})$$

$$K_2 = -\ 0.000169L^3 + 0.00632L^2 - 0.0862L + 0.978 \quad (D = 0.370 \text{ in.})$$

The constants for the tubing tested and their empirical relations are presented graphically in Fig. 11. The empirical relations for $P_{R_{max}}$ are presented in Fig. 10.

The effect of tube length and diameter on the response pressure can be seen in Fig. 10. This figure indicates that tube diameter has a greater effect on $P_{R_{max}}$ than tube length. When the diameter of the one foot tube is decreased from 0.370 in. to 0.242 in., $P_{R_{max}}$ is decreased from 710 psig to 395 psig for an input pressure of 800 psig. However, when the 0.370 in. diameter tube is increased from one to 15 ft., $P_{R_{max}}$ is decreased from 710 psig to 427 psig for the same input pressure.

CHAPTER V

CONCLUSIONS

The conclusions reached are necessarily restricted to the size of the specimen and the one volume size (10.55 cu. in.) tested, shock tube pressures ranging from 50 to 1000 psig, and the accuracy of the instrumentation. Within these limitations it may be concluded that:

1. The maximum response pressure can be approximated by the empirical relation

$$P_{R_{max}} = CP_{I_{max}}^{0.964}$$

or by the more simple, but less accurate, empirical relation

$$P_{R_{max}} = KP_{I_{max}}$$

2. The constants C and K are functions of test system geometry and can be represented by the following empirical relations:

$$C_1 = -0.000082L^3 + 0.00319L^2 - 0.0528L + 0.675 \ (D = 0.242 \text{ in.})$$

$$C_2 = -0.000262L^3 + 0.00942L^2 - 0.1198L + 1.239 \ (D = 0.370 \text{ in.})$$

$$K_1 = -0.000060L^3 + 0.00231L^2 - 0.0400L + 0.536 \ (D = 0.242 \text{ in.})$$

$$K_2 = -0.000169L^3 + 0.00632L^2 - 0.0862L + 0.978 \ (D = 0.370 \text{ in.})$$

3. Tube diameter has much more effect on $P_{R_{max}}$ than tube length.

CHAPTER VI

RECOMMENDATIONS

The plumbing found in typical pressure-sensing systems is composed of lengths of small diameter tubing connected with standard fittings. It is recommended that a study be conducted to determine the pressure attenuation and lag of shock waves in a system consisting of tubing and standard tee and elbow fittings.

Since this study was conducted with only two tube diameters and one volume size, it is recommended that further studies be conducted with a larger number of tube diameters and volume sizes. It is also recommended that further analytical study of this research be conducted to obtain a theoretical relation of $P_{R_{max}}$ as a function of $P_{I_{max}}$ and test system geometry.

APPENDIX

Table 1. Tubing Tested

Length (ft.)	Inside Diameter (in.)
1	0.242
1	0.370
5	0.242
5	0.370
10	0.242
10	0.370
15	0.242
15	0.370

Table 2. Amplifier Attenuation Settings

Shock Tube Pressure (psig)	Amplifier Attenuation Setting
50	1
100	1
200	2
500	5
700	7
1000	10

Table 3. Diaphragm Thickness

Shock Tube Pressure (psig)	Total Diaphragm Thickness (mils)
50	3
100	6
200	10
500	21.5
700	30
1000	45

FIG. 1. GENERAL LAYOUT

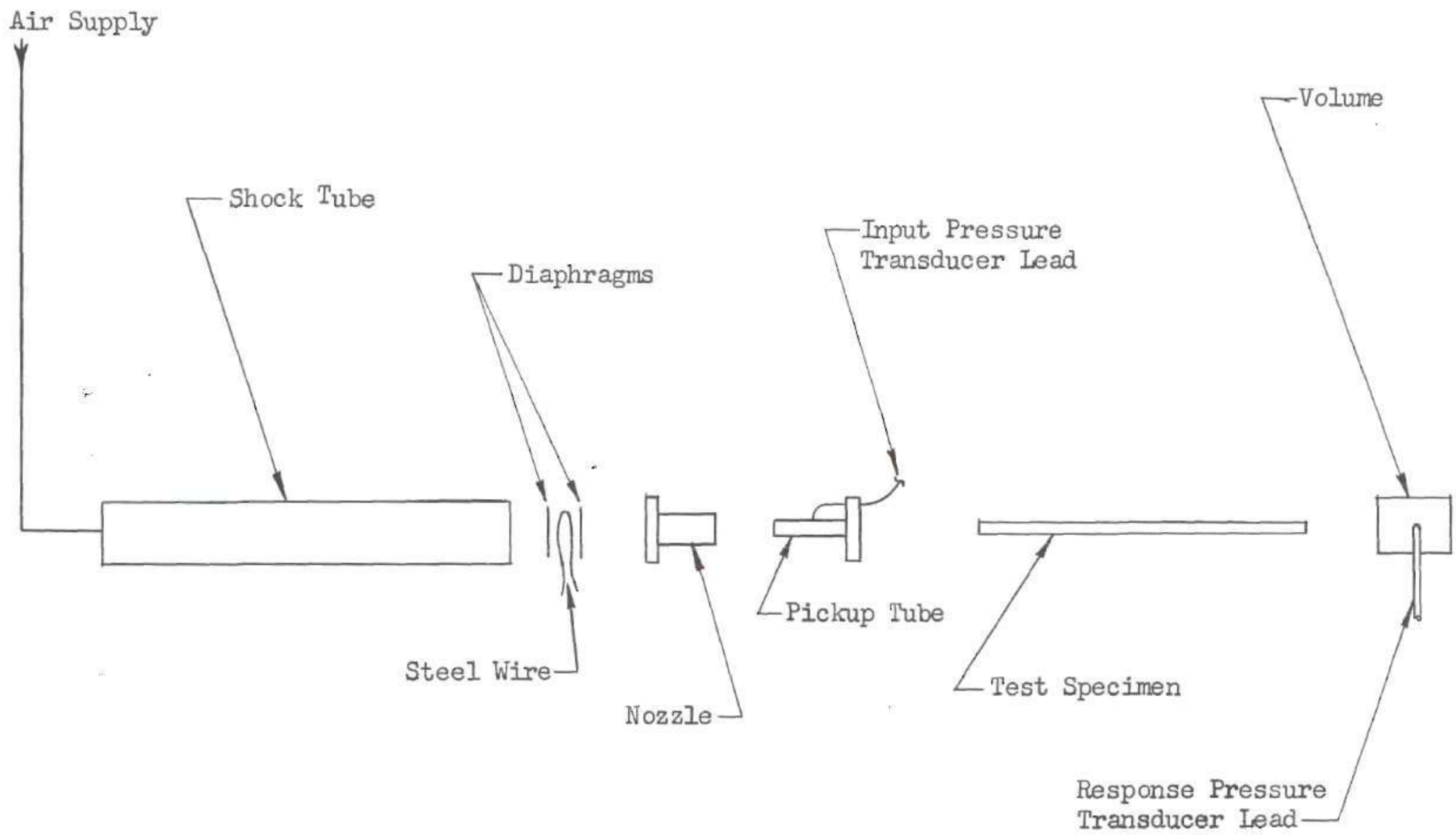

FIG. 2. TEST APPARATUS

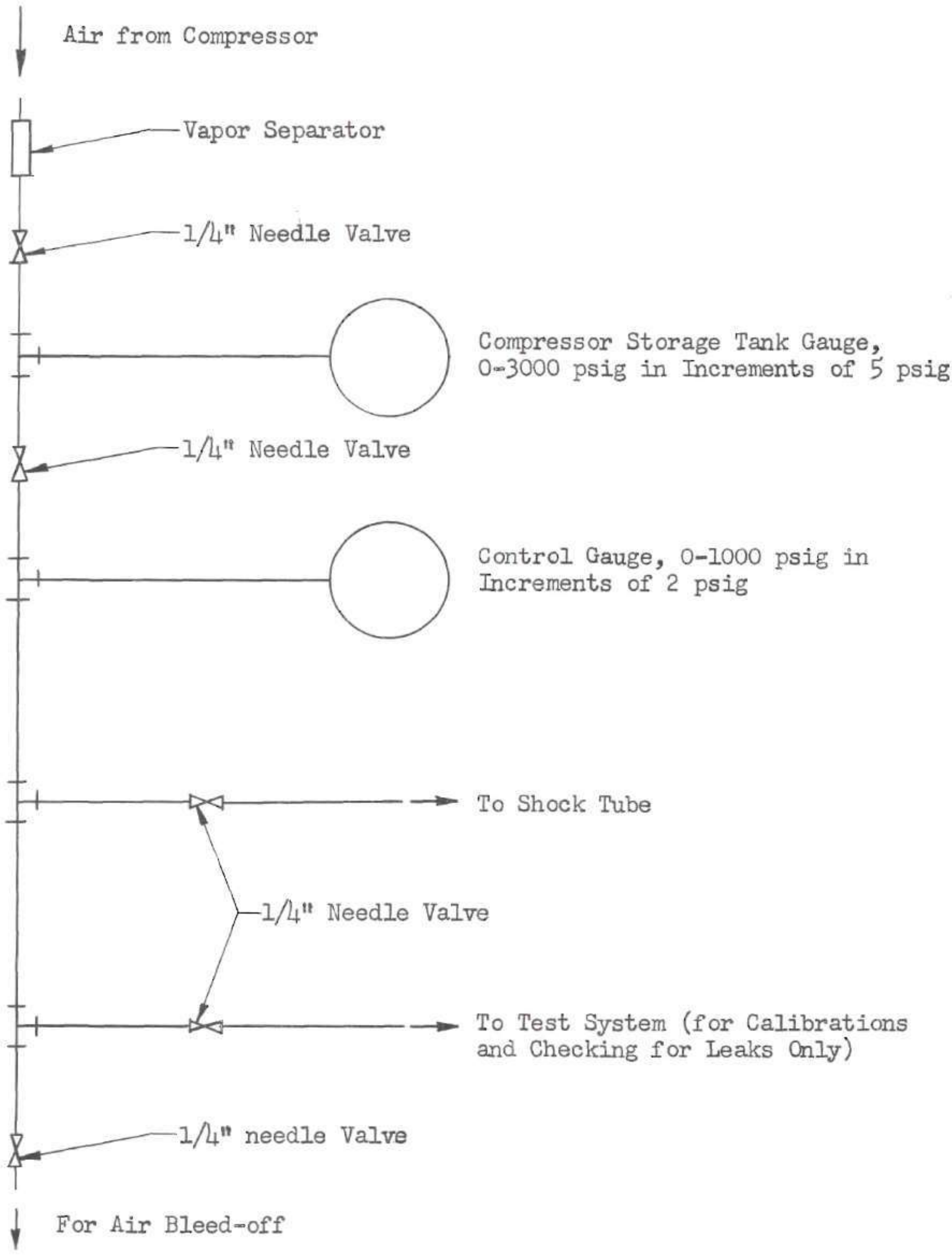

FIG. 3. CONTROL BOARD

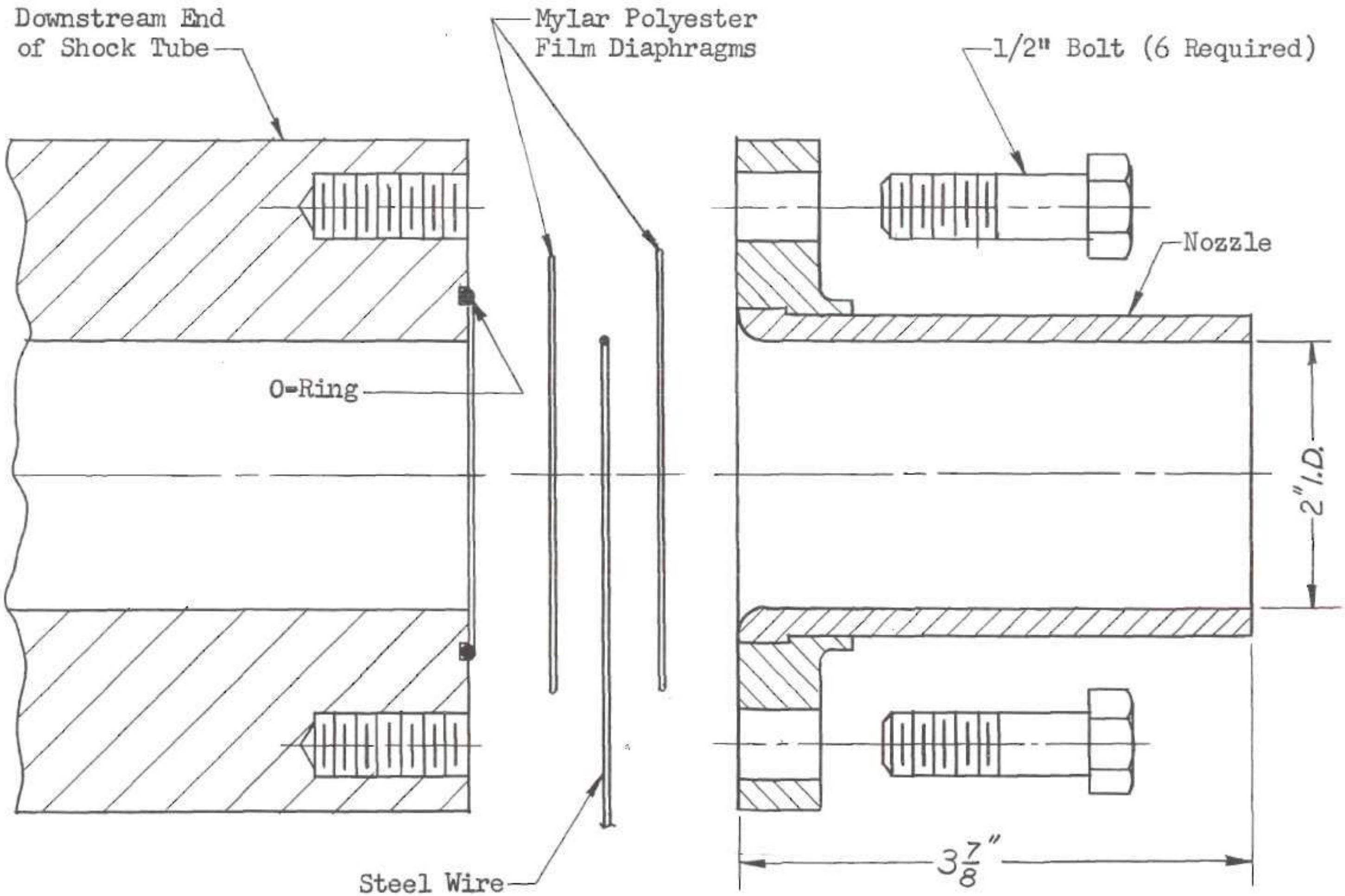

FIG. 4. DETAIL OF NOZZLE

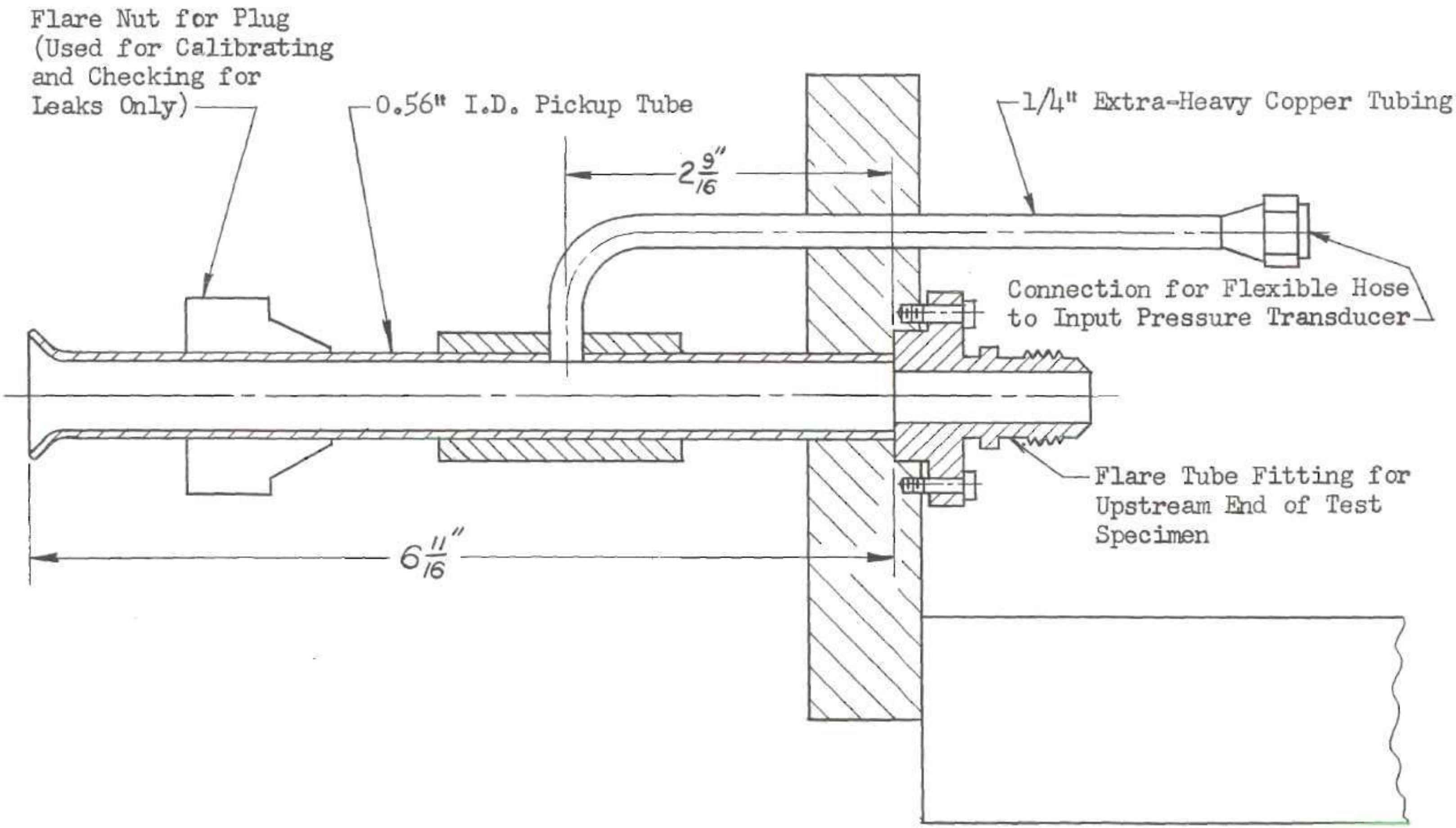

FIG. 5. DETAIL OF PICKUP TUBE

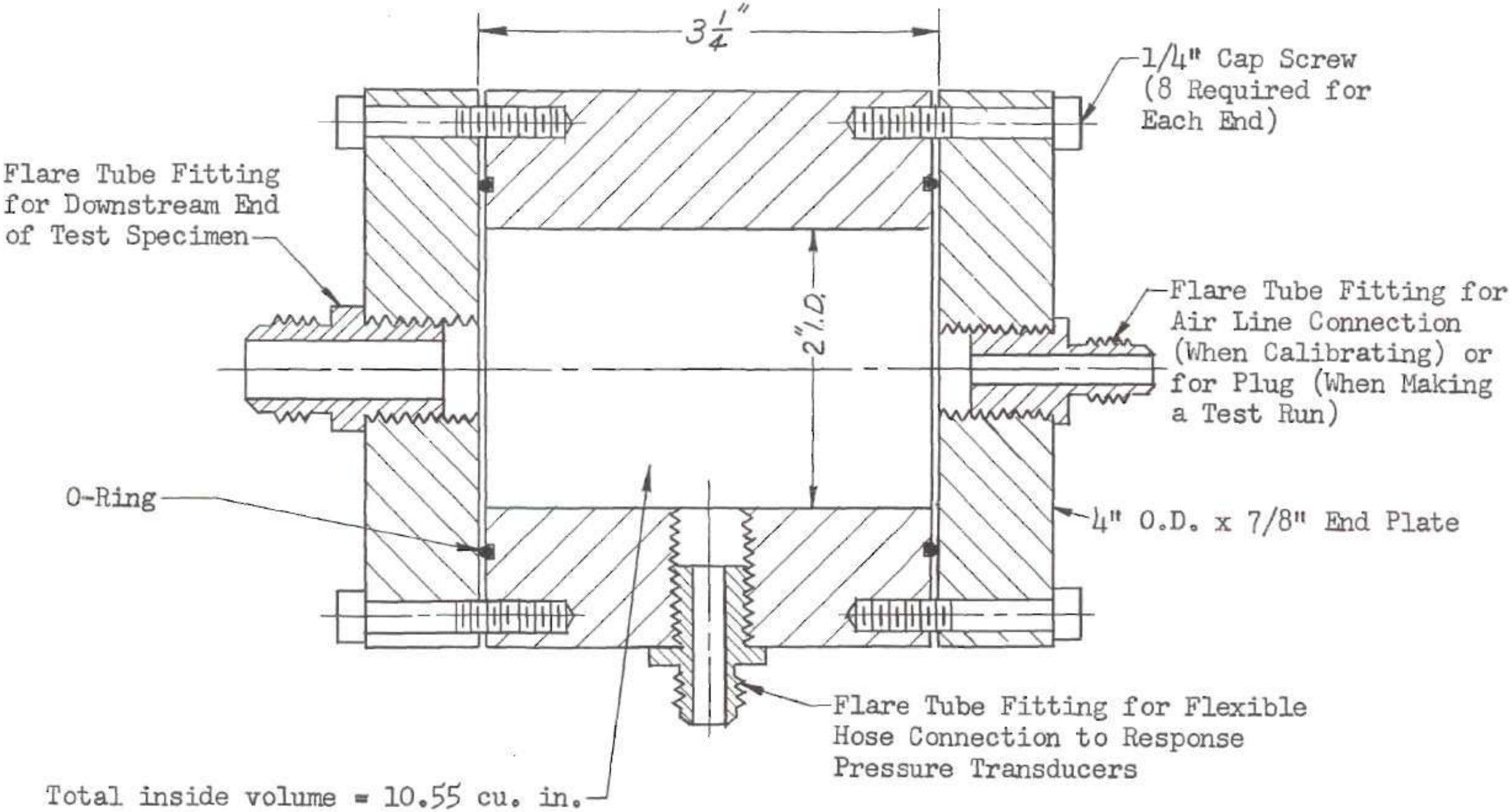

FIG. 6. DETAIL OF VOLUME

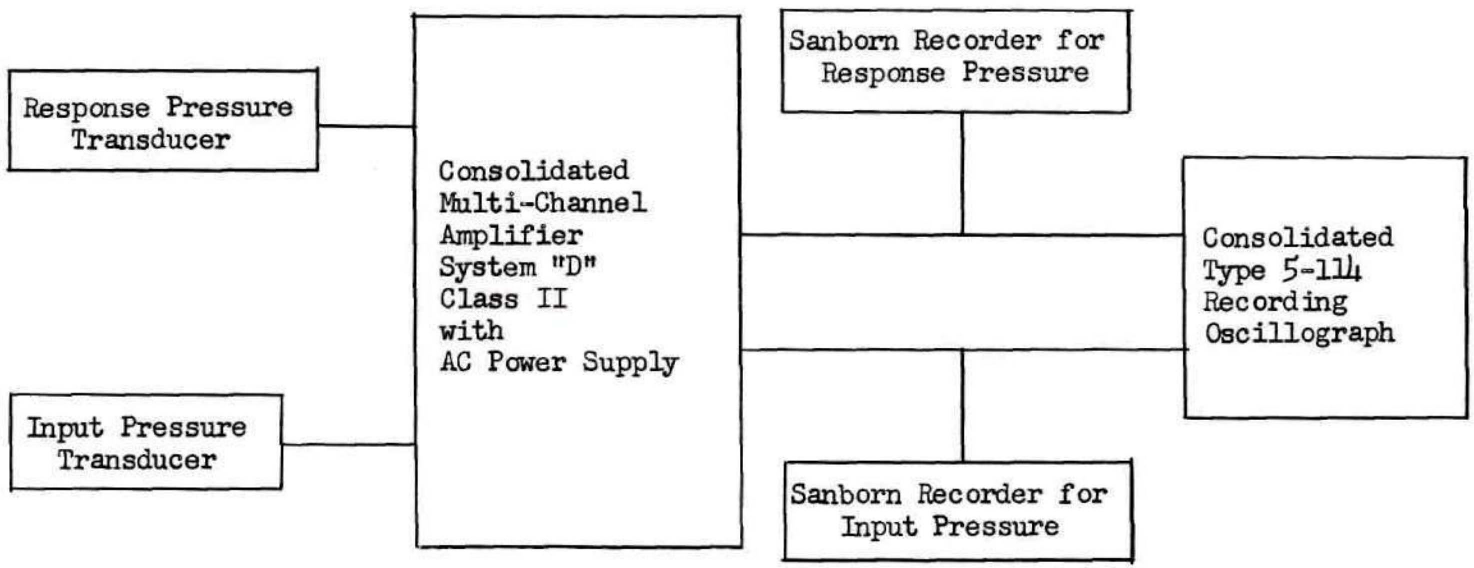

FIG. 7. INSTRUMENTATION CIRCUIT

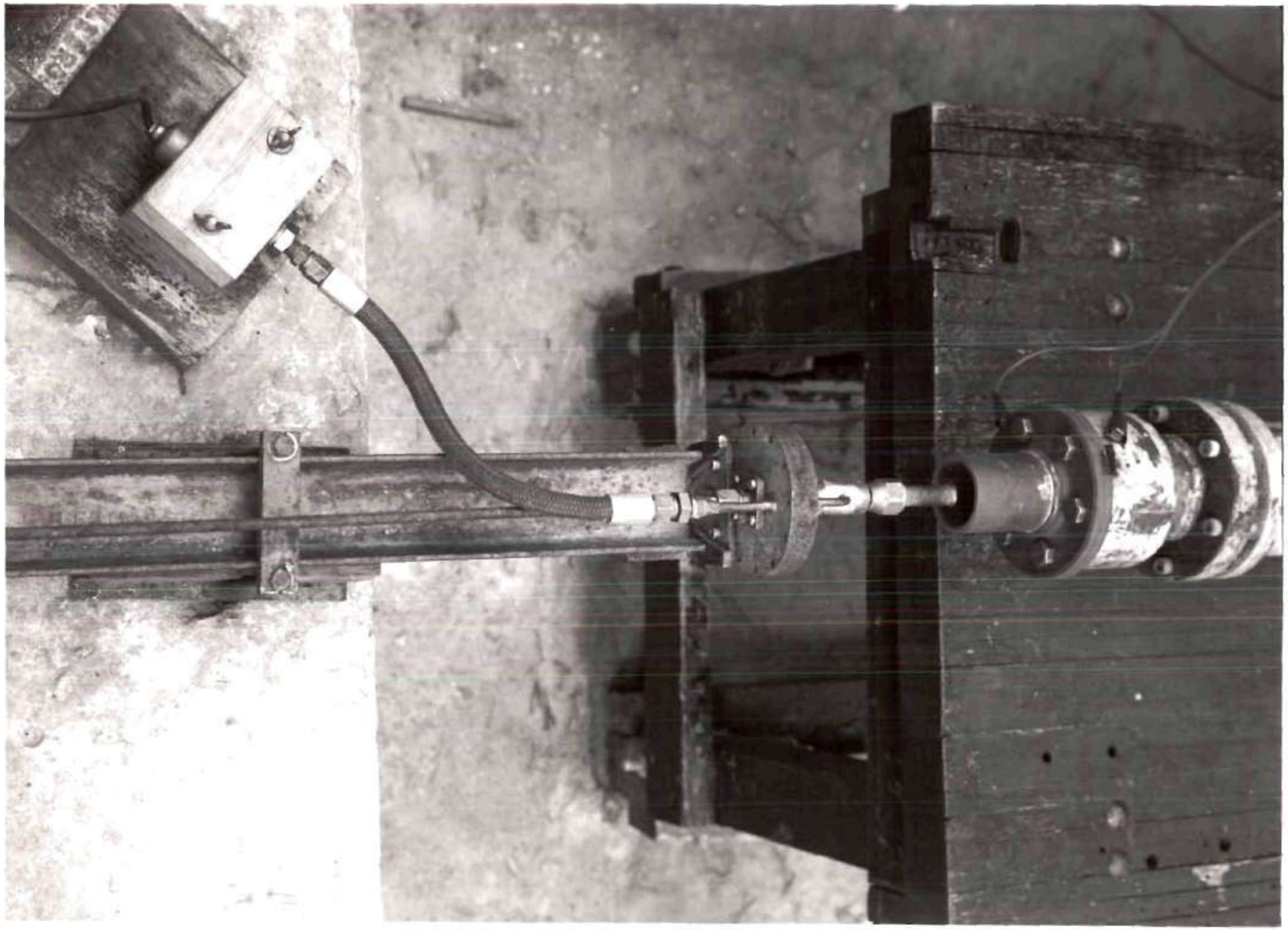

FIG. 8. ARRANGEMENT OF PICKUP TUBE

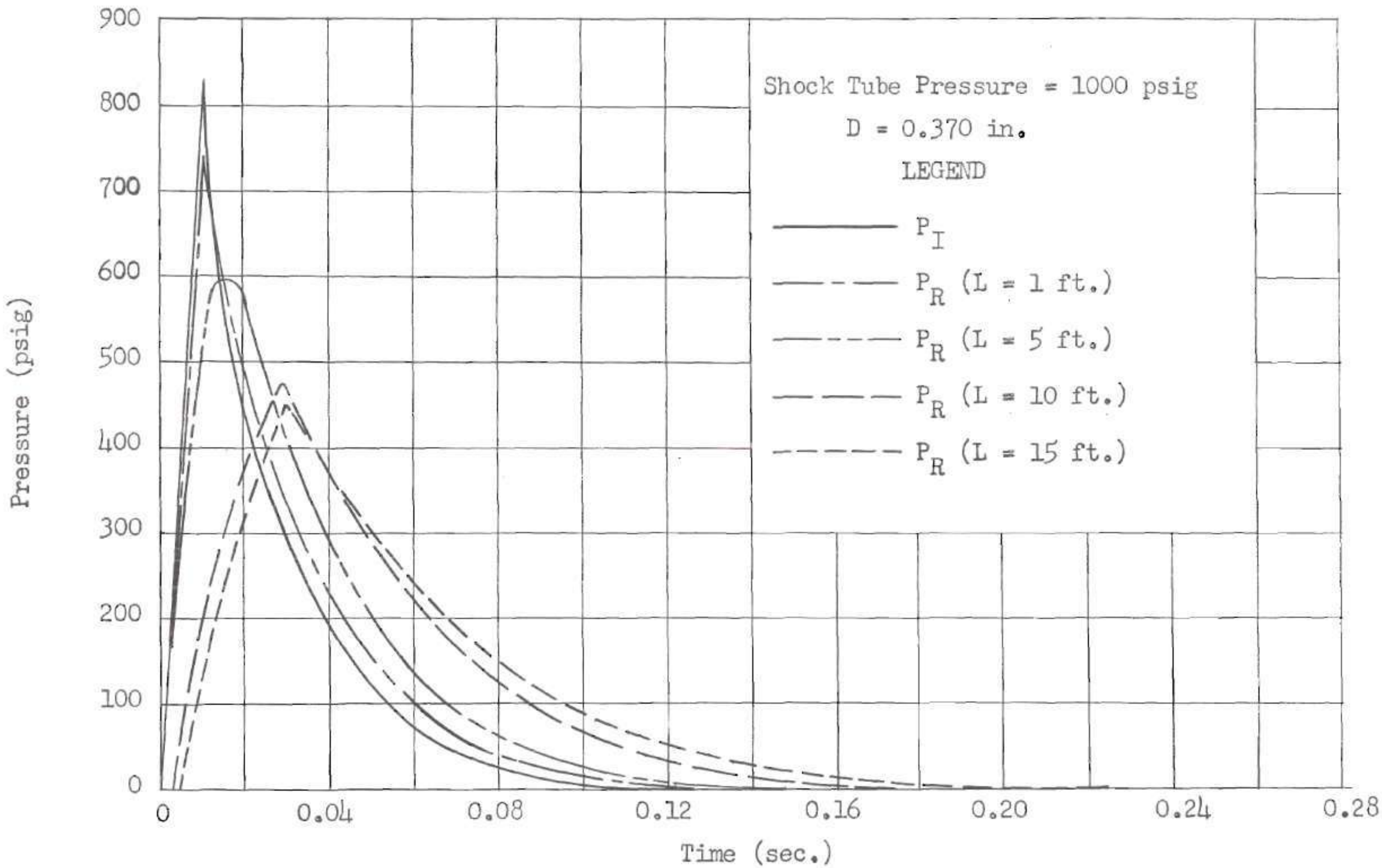

FIG. 9. TYPICAL PRESSURE TRACES

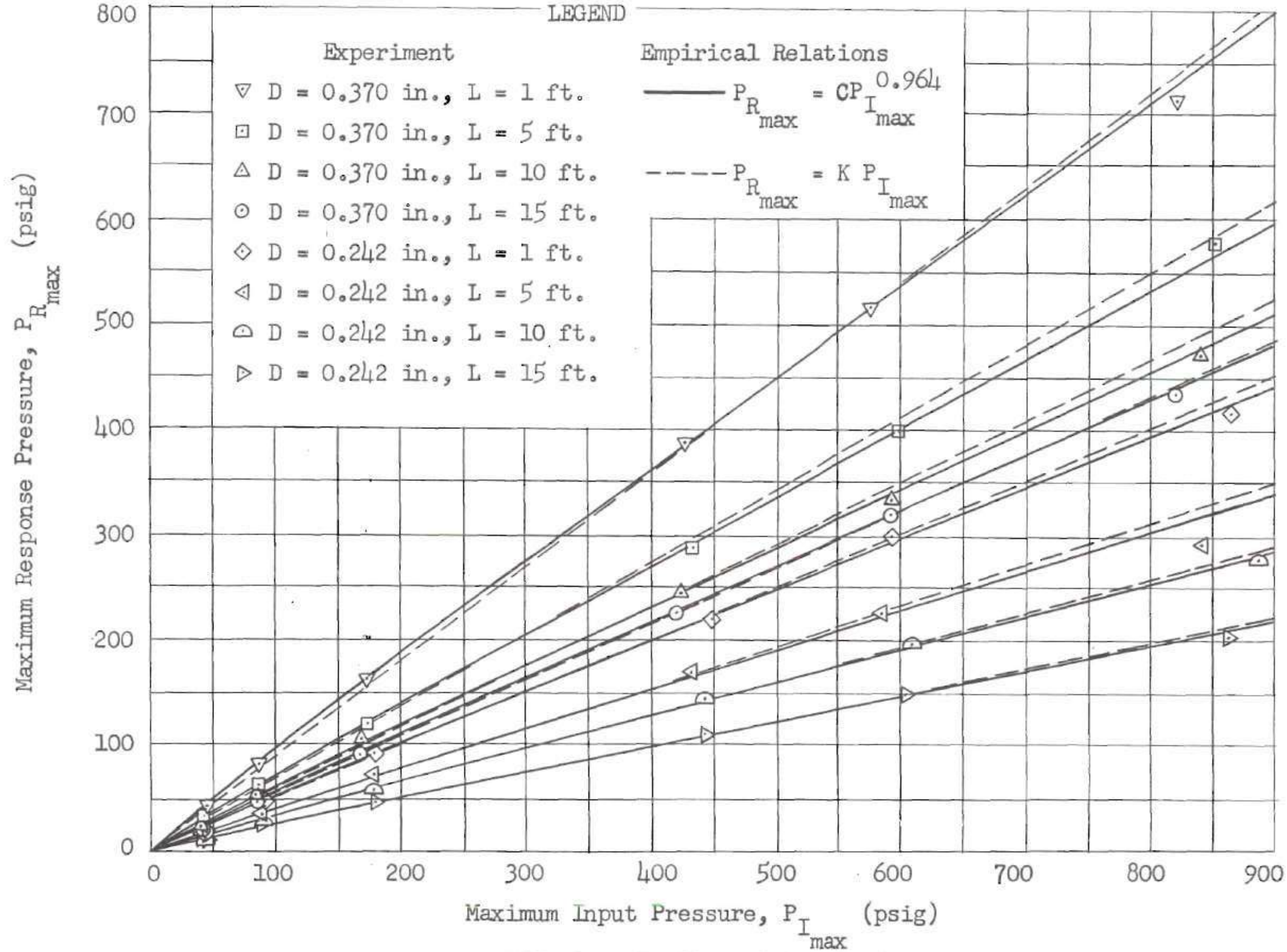

FIG. 10. PRESSURE ATTENUATION

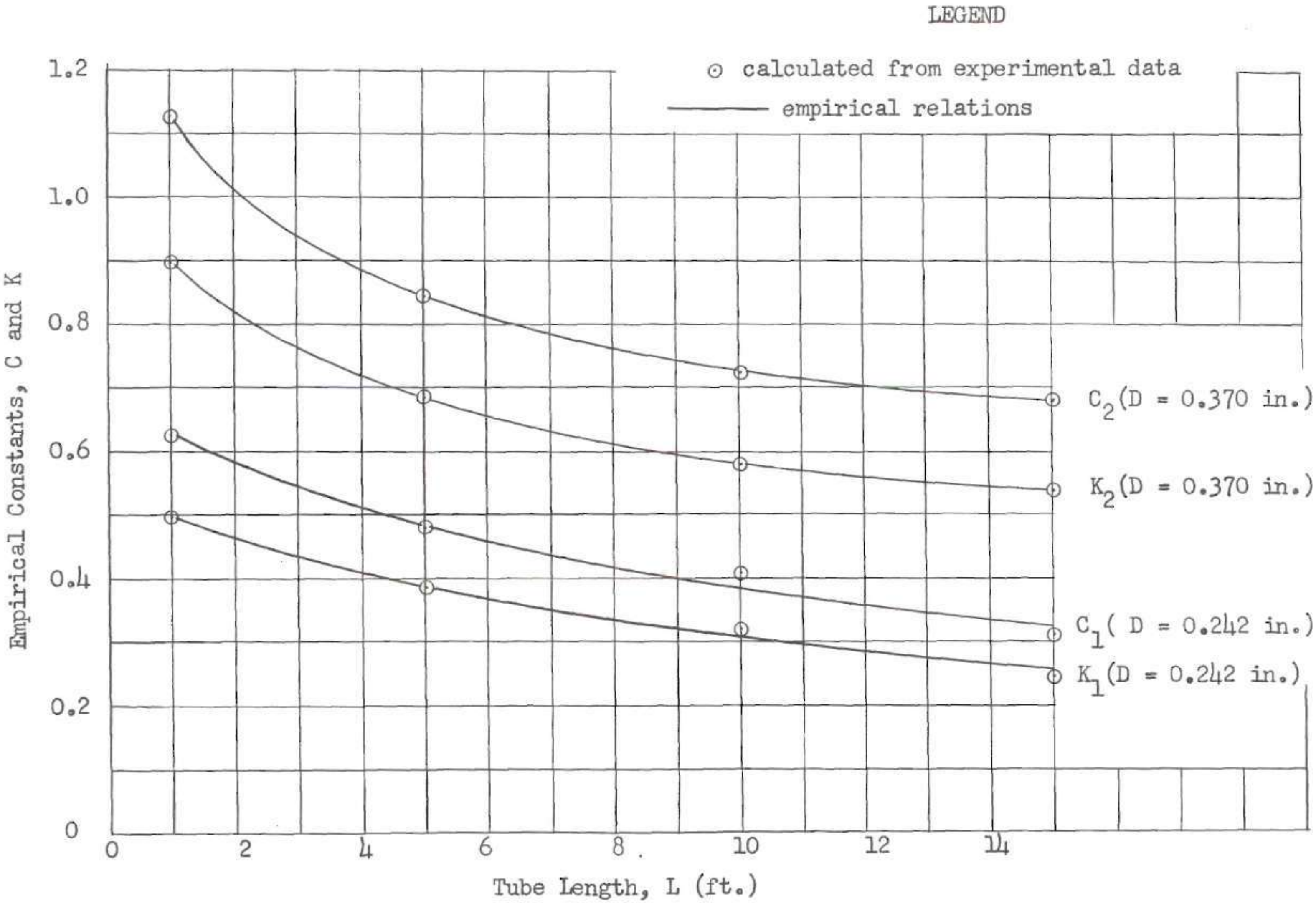

FIG. 11. EMPIRICAL CONSTANTS VS TUBE LENGTH

REFERENCES

1. Kilburg, R.F., An Experimental Investigation of Pressure Attenuation in Typical Missile Plumbing Systems Subjected to Shock Wave Inputs - Part II, Unpublished Masters Thesis, Georgia Institute of Technology, 1958.